EV323498882US

HUMANIZED ANTIBODIES AGAINST HUMAN 4-1BB

This invention claims the benefit of U.S. Provisional Application No. 60/399,646 filed July 30, 2002, whose contents are hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION:

The invention is directed to humanized antibodies and, more specifically, to humanized antibodies to human 4-1BB.

An extensive body of evidence has unequivocally demonstrated that some degree of immune response against cancer exists in humans and animals. In cancer patients, cellular components of the immune system are able to recognize antigens expressed by tumor cells, such as differentiation or oncofetal antigens, or mutated gene products (S. Rosenberg, Nature, 411:380 (2001)). A number of clinical studies have shown that tumor-infiltrating lymphocytes have favorable prognostic significance (E. Halapi, Med. Oncol., 15:203 (1998); J. Resser et al., Curr. Opin. Oncol., 10:226 (1998); D. Elder, Acta Oncol., 38:535 (1999); L. Zhang et al., New Engl. J. Med., 348:203-213(2003)). Furthermore, clinical results with immunomodulators (bacterial products or biological response modifiers such as cytokines) led to tumor regression in a number of patients (S. A. Rosenberg, Cancer J. Sci. Am. 6 (S):2 (2000); P. Bassi, Surg. Oncol.11:77 (2002); Fishman M, and S. Antonia, Expert Opin Investig Drugs. 12:593 (2003). Despite these responses, immunity against cancer frequently fails to effectively eliminate tumor cells. Among the known causes of immune failure against cancer is the lack of co-stimulatory molecules on tumors, which results in the inability of the tumor cells to effectively stimulate T cells. Recent advances in our understanding of the requirements for tumor antigen recognition and immune effector function indicate that a potential successful strategy to enhance an anti-tumor immune response is providing co-stimulation through an auxiliary molecule.

The current model for T cell activation postulates that for an induction of full activation, naive T cells require two signals: a signal provided through the binding of processed antigens presented to the T-cell receptor by major histocompatibility complex (MHC) class I molecules (signal 1); and an additional signal provided by the

23914
PATENT TRADEMARK OFFICE

interaction of co-stimulatory molecules on the surface of T-cells and their ligands on antigen presenting cells (signal 2) (D. Lenschow et al., Annu. Rev. Immunol., 14:233-258, (1996); C. Chambers et al., Curr. Opin. Immunol., 9:396-404 (1997)). Recognition of an antigen by a naive T cell is insufficient in itself to trigger T-cell activation. Without the second co-stimulatory signal, T cells may be eliminated either by promoting its death or by inducing anergy (A. Abbas et al., Cellular and Molecular Immunology, 3rd ed., 139-170, (1997)).

4-1BB, also referred to as CD137, is a member of the tumor necrosis factor receptor (TNFR) gene family which includes proteins involved in regulation of cell proliferation, differentiation, and programmed cell death (A. Ashkenazi, Nature, 2:420-430, (2002)). 4-1BB is expressed predominantly on activated T cells, including both CD4+ and CD8+ cells, NK cells, and NK T cells (B. Kwon et al., Mol. Cell, 10:119-126, (2000); J. Hurtado et al, J. Immunol. 155:3360-3365, (1995); L. Melero et al., Cell. Immunol. 190:167-172, (1998)). In addition, 4-1BB has been detected on dendritic cells (T. Futagawa et al., Int. Immunol. 14:275-286, (2002); R. Wilcox et al., J Immunol. 168:4262-4267, (2002); M. Lindstedt et al., Scand. J. Immunol. 57:305-310, (2003)), macrophages, activated eosinophils, and intra-epithelial lymphocytes (K. Pollok et al., J. Immunol. 150:771-781 (1993); D. Vinay et al., Semin. Immunol. 10:481-489, (1998)). Naive, resting T-cells do not express the receptor, which is up-regulated upon activation. Signaling through 4-1BB was demonstrated to induce T-cell proliferation, induction of interferon-gamma (IFN-γ) synthesis, and inhibition of activated cell death in murine and human T-cells (Y. Kim et al., Eur. J. Immunol. 28:881-890, (1998); J. Hurtado et al., J. Immunol., 158:2600-2609, (1997); C. Takahashi et al., J. Immunol., 162:5037, (1999)). The natural ligand for 4-1BB, 4-1BB ligand (4-1BBL), is a member of the TNF superfamily and is detected mainly on activated antigen-presenting cells, such as B cells, macrophages, and dendritic cells (M. Alderson et al., Eur. J. Immunol., 24:2219-2227 (1994); K. Pollok, et al., Eur. J. Immunol. 24:367-374 (1994)) but also in murine B-cell lymphomas, activated T-cells, and human carcinoma lines of epithelial origin (M. DeBenedette et al., J. Immunol. 158:551-559 (1997); H. Salih et al., J. Immunol. 2903-2910 (2000)).

In vivo efficacy studies in mice have demonstrated that treatment with anti-4-1BB antibodies led to tumor regressions in multiple tumor models, indicating the

potential use of this therapy for the treatment of cancer. Of note, anti-murine 4-1BB antibodies were shown to induce an immune response against tumors that were poorly or non-immunogenic (I. Melero et al., Nat Med. 3:682-685, (1997); R. Wilcox et al., J. Clin. Invest. 109:651-659, (2002)). Anti-murine 4-1BB antibodies that showed anti-tumor activity were shown to enhance IFN-gamma synthesis in vitro. A number of reports have unequivocally demonstrated that in vivo induction of IFN-gamma by treatment with anti-4-1BB antibodies is critical for the production of an effective anti-tumor immune response (R. Wilcox et al., Cancer Res. 62:4413 (2002); R. Miller et al., J Immunol. 169:1792 (2002) and studies reported here). Neutralization of IFN-gamma activities significantly reduced the antitumor effects observed with anti-4-1BB antibodies in several tumor models, revealing a correlation between in vitro functional effects, i.e., induction of IFN-gamma, and in vivo anti-tumor efficacy. There is ample in vitro evidence that binding of human 4-BB to its natural ligand or anti-human 4-1BB antibodies produce similar functional effects to that observed with anti-murine 4-1BB antibodies (Y. Kim et al., Eur. J. Immunol. 28:881 (1998); Y. Wen et al., J. Immunol. 168:4897 (2002)). However, most of the anti-human 4-1BB antibodies reported have been raised in rodents which made them unsuitable for human treatment. One report demonstrated that administration of a humanized anti-human 4-1BB antibody in vivo induced suppression of T-cell dependent immunity in nonhuman primates, an effect also observed with anti-murine 4-1BB antibodies (H. Hong et al., J Immunother. 23:613-621 (2000)).

Consequently, based on the roles of 4-1BB in modulating the immune response and the demonstration of efficacy in murine tumor models, it would be desirable to produce anti-human 4-1BB antibodies with agonistic activities that could be used for the treatment or prevention of human diseases like cancer.

BRIEF SUMMARY OF THE INVENTION:

The present invention provides humanized antibodies that bind to human 4-1BB (H4-1BB) and that allow binding of H4-1BB to a human 4-1BB ligand (H4-1BBL). Thus, the invention is directed to antibodies that bind to H4-1BB and that do not block the binding of H4-1BB to its H4-1BBL, thereby permitting the binding of both an antibody of the invention and H4-1BBL to H4-1BB. The antibodies of the

invention bind to H4-1BB with high affinity and/or induce interferon-gamma synthesis (IFN-γ), i.e., have agonist activity, but do not block the interaction between H4-1BB and H4-1BBL. These antibodies can be used as immuno-enhancers of an anti-tumor immune response.

In one aspect, the antibody comprises a light chain and a heavy chain, wherein: said heavy chain includes a CDR1 (complementary determining region 1) comprising amino acids 50 to 54 of SEQ ID NO:5, a CDR2 (complementary determining region 2) comprising amino acids 69 to 85 of SEQ ID NO:5, and a CDR3 (complementary determining region 3) comprising amino acids 118 to 122 of SEQ ID NO:5; and said light chain includes a CDR1 (complementary determining region 1) comprising amino acids 44 to 60 of SEQ ID NO:8, a CDR2 (complementary determining region 2) comprising amino acids 76 to 82 of SEQ ID NO:8, and a CDR3 (complementary determining region 3) comprising amino acids 115 to 123 of SEQ ID NO:8.

In another aspect, the humanized antibody is an IgG4 antibody.

In yet another aspect, the antibody comprises the amino acid sequences of SEQ ID NO:5 and SEQ ID NO:8.

In another aspect, the humanized antibody is hu39E3.G4. This humanized antibody presents high affinity for H4-1BB, i.e., specifically binds H4-1BB, and effectively induces IFN-γ synthesis, but does not affect the binding of H4-1BB to its corresponding ligand, H4-1BBL, and does not fix complement, i.e., is of the IgG4 isotype. Thus, hu39E3.G4 is a non-blocking, agonist anti-4-1BB antibody that is capable of inducing T cell proliferation and cytokine production.

The invention also provides pharmaceutical compositions comprising an antibody of the invention, or an antigen-binding portion thereof, and a pharmaceutically acceptable carrier. The pharmaceutical composition can be administered alone or in combination with an agent, e.g., an agent for treating cancer such as a chemotherapeutic agent or a vaccine.

The antibodies of the invention have wide therapeutic applications as immunomodulators of diseases such as cancer, autoimmune diseases, inflammatory diseases, and infectious diseases. Because of the expression of H4-1BB seen on effector $CD8^+/CD4^+$ T cells and NK cells, the potential oncology applications of anti-

H4-1BB antibodies are evident. The invention further provides methods for treating cancer in a subject comprising administering a therapeutically effective amount of the antibody of the invention to said subject. In one aspect, this method further comprises administering a vaccine. Suitable vaccines include, for example, a tumor cell vaccine, a GM-CSF-modified tumor cell vaccine, or an antigen-loaded dendritic cell vaccine. The cancer can be, for example, prostate cancer, melanoma, or epithelial cancer.

The invention also provides isolated polynucleotides comprising a nucleotide sequence selected from the group consisting of: (a) nucleotides 693 to 2072 of SEQ ID NO:3; and (b) nucleotides 633 to 1034 and 1409 to 1726 of SEQ ID NO:6. The invention further provides isolated polynucleotides that comprise the nucleotide sequence of SEQ ID NO:3 or SEQ ID NO:6.

The invention also provides isolated polypeptides comprising an amino acid sequence selected from the group consisting of SEQ ID NO:5 and SEQ ID NO:8.

The invention further provides a humanized immunoglobulin having binding specificity for H4-1BB, said immunoglobulin comprising an antigen binding region of nonhuman origin. In one aspect, the immunoglobulin further comprises a portion of human origin. In another aspect, the immunoglobulin is a Fab fragment (antigen binding fragment) of an antibody of the invention.

The invention also provides a hybridoma cell line that produces an H4-1BB antibody. In one aspect, the hybridoma cell line is rat hybridoma 39E3 deposited with the ATCC and having Accession Number ATCC-PTA-5326. The invention further provides hybridoma cell lines wherein the hybridoma produces an antibody that specifically binds to H4-1BB or binding fragment thereof.

All deposits referred to herein were made with the American Type Culture Collection (ATCC), Manassas, Va. 20110 USA and will be maintained under the terms of the Budapest Treaty on the International Recognition of the Deposit of Micro-Organisms for purposes of Patent Procedure. These deposits are provided merely as convenience to those of skill in the art and are not an admission that such a deposit is required under 35 U.S.C. § 112. The sequences of the polynucleotides contained in the deposited materials, as well as the amino acid sequence of the polypeptides encoded thereby, are incorporated herein by reference and are controlling in the event of any conflict with any description of sequences herein. A

license may be required to make, use, or sell the deposited materials, and no such license is hereby granted.

BRIEF DESCRIPTION OF THE DRAWINGS:

FIG. 1 shows a plasmid map of pD17-H39E3-2.h4a.

FIGS. 2A-2G show the nucleotide sequence of the plasmid pD17-H39E3-2.h4a (coding strand (SEQ ID NO:3) and complementary strand (SEQ ID NO:4)) and the heavy chain amino acid sequence (SEQ ID NO:5) encoded by nucleotides 693 to 2071 of the coding strand (SEQ ID NO:3). As shown in FIGS. 2A-2G, the heavy chain amino acid sequence includes a CDR1 comprising amino acids 50 to 54 of SEQ ID NO:5, a CDR2 comprising amino acids 69 to 85 of SEQ ID NO:5, and a CDR3 comprising amino acids 118 to 122 of SEQ ID NO:5.

FIG. 3 shows a plasmid map of pD16-H39E3.L1.

FIGS. 4A-4H show the nucleotide sequence of the plasmid pD16-H39E3.L1 (coding strand (SEQ ID NO:6) and complementary strand (SEQ ID NO:7)) and the light chain amino acid sequence (SEQ ID NO:8) encoded by nucleotides 633 to 1034 and 1409 to 1726 of the coding strand (SEQ ID NO:6). As shown in FIG. 4A-4H, the light chain amino acid sequence includes a CDR1 comprising amino acids 44 to 60 of SEQ ID NO:8, a CDR2 comprising amino acids 76 to 82 of SEQ ID NO:8, and a CDR3 comprising amino acids 115 to 123 of SEQ ID NO:8.

FIG. 5 shows the binding affinities of anti-human-4-1BB antibodies at 100 nM concentration to immobilized H4-1BB.

FIG. 6 shows that mAb 39E3 (parental antibody) (A) and hu39E3.G4 antibody (B) bind to PMA and ionomycin-stimulated CEM cells.

FIG. 7 shows the induction of IFN-γ by co-stimulation of human T-cells with anti-CD3 and anti-4-1BB mAb 39E3 and hu39E3.G4.

FIGS. 8A and 8B show the anti-tumor effect of antibody 1D8 against the M109 lung carcinoma model as a single agent (FIG. 8A) or in mice previously immunized with irradiated M109 tumor cells (FIG. 8B).

FIGS. 9A and 9B show the anti-tumor effect of antibody 1D8 against the Lewis Lung/LM lung carcinoma model as a single agent (FIG. 9A) or in mice previously immunized with irradiated Lewis Lung/LM tumor cells (FIG. 9B).

FIG. 10 shows that the anti-tumor effect of mAb 1D8 is reduced in the presence of an IFN-γ neutralizing antibody.

DETAILED DESCRIPTION OF THE INVENTION:

The invention is directed to the preparation and characterization of a humanized immunoglobulin for use in the treatment of cancer, which immunoglobulin is specifically capable of binding to H4-1BB. The humanized antibody, hu39E3.G4, of the present invention, like its parental rat mAb (39E3), presents high affinity for H4-1BB and effectively induces IFN-γ production in co-stimulatory assays, but does not affect the binding of H4-1BB to its corresponding ligand, H4-1BBL and does not fix complement. The antibody comprises two pairs of light chain/heavy chain complexes, at least one chain comprising one or more rat complementary determining regions (CDRs) functionally joined to human framework region segments.

The immunoglobulin, including binding fragments and other derivatives thereof, of the invention may be produced readily by a variety of recombinant DNA techniques, with ultimate expression in transfected cells, preferably immortalized eukaryotic cells, such as myeloma or hybridoma cells. Polynucleotides comprising a first sequence coding for humanized immunoglobulin framework regions and a second sequence set coding for the desired immunoglobulin complementary determining regions can be produced synthetically or by combining appropriate cDNA and genomic DNA segments.

The humanized antibody of the invention may be used alone in substantially pure form, or together with other therapeutic agents such as radiotherapy, hormonal therapy, cytotoxic agents, vaccines, and other immunomodulatory agents, such us cytokines and biological response modifiers. These compounds will be particularly useful in treating cancer or other immune-proliferative disorders. The humanized antibody complexes can be prepared in a pharmaceutically acceptable dosage form, which will vary depending on the mode of administration.

As used herein, "humanized" antibodies comprise antibodies with human framework regions combined with CDRs from a donor mouse or rat immunoglobulin (See, for example, U.S. Patent No. 5,530,101). Encompassed within the scope of the

present invention are humanized antibodies which comprise CDRs derived from the rodent variable chains disclosed herein.

As used herein the term "treating" includes the administration of the compounds or agents of the invention to prevent or delay the onset of symptoms, complications, or biochemical indicia of a disease, alleviating the symptoms or arresting or inhibiting further development of the disease, condition, or disorder (e.g., cancer). Treatment may be prophylactic (to delay the onset of the disease or to prevent the manifestation of clinical or subclinical symptoms thereof) or therapeutic suppression or alleviation of symptoms after the manifestation of the disease.

As used herein the term "specific binding" refers to an antibody binding to a predetermined antigen. When referring to a peptide, the term refers to a peptide molecule which has intermediate or high binding affinity to a target molecule. The phrase "specifically binds to" refers to a binding reaction which is determinative of the presence of a target protein in the presence of a heterogeneous population of proteins and other biologics. Thus, under designated assay conditions, the specified binding moieties bind preferentially to a particular target protein and do not bind in a significant amount to other components present in a test sample.

The term "recombinant humanized antibody" includes all humanized antibodies of the invention that are prepared, expressed, created or isolated by recombinant means, such as antibodies isolate from an animal (e.g. a mouse); antibodies expressed using a recombinant expression vector transfected into a host cell, antibodies isolated from a recombinant, combinatorial human antibody library, or antibodies prepared, expressed, created or isolated by any other means that involves splicing of human immunoglobulin gene sequences to other DNA sequences. Such recombinant human antibodies have variable and constant regions (if present) derived from human germline immunoglobulin sequence. Such antibodies can, however, be subjected to *in vitro* mutagenesis (or, when an animal transgenic for human Ig sequences is used, *in vivo* somatic mutagenesis) and thus the amino acid sequences of the VH (antibody heavy chain variable region) and VL (antibody light chain variable region) of the recombinant antibodies are sequences that, while derived from and related to human germline VH and VL sequences, may not naturally exist within the human antibody germline.

The most straightforward approach to humanizing an antibody consists of grafting the CDRs from the donor mAb onto a human framework (P. Jones et al., Nature 321:522-525 (1986)). However, certain framework residues support CDR structure, and contact antigen grafting rodent CDRs onto human framework templates may diminish the binding activity of the resulting humanized mAb (J. Foote et al., J. Mol. Biol. 224:487-499 (1992)). Because of this, the potential contribution of specific framework residues to antibody structure and affinity can be assessed by structural modeling.

The invention encompasses a humanized antibody with additional conservative amino acid substitutions that have substantially no effect on H4-1BB binding. Conservative substitutions typically include the substitution of one amino acid for another with similar characteristics, e.g., substitutions within the following groups: valine, glycine; glycine, alanine; valine, isoleucine, leucine; aspartic acid, glutamic acid; asparagine, glutamine; serine, threonine; lysine, arginine; and phenylalanine, tyrosine.

Also encompassed within the invention are the disclosed heavy and light chain variable regions and active or functional parts thereof. The immunologically competent or functional form of the protein or part thereof is also referred to herein as a "light/heavy chain variable region or biologically active portion thereof". In the present case, a biologically active portion thereof comprises a portion of said light or heavy chain which, when incorporated into an antibody, still permits the antibody to bind to H4-1BB.

Specifically encompassed within the present invention are nucleic acid sequences encoding the variable heavy chain (SEQ ID NO:3) and the variable light chain (SEQ ID NO:6) of an antibody of the present invention. Also encompassed within the present invention are plasmids comprising the polynucleotides shown in SEQ ID NO:3 and SEQ ID NO:6 and having ATCC Accession Numbers ATCC-PTA-5325 and ATCC-PTA-5324, respectively.

A humanized antibody that binds to H4-1BB and that comprise polypeptides that are substantially homologous to, or that show substantial sequence identity to, the variable light and heavy chain sequences disclosed herein are also contemplated by the present invention. For example, a humanized antibody comprising a light chain

region that exhibits at least about 85% sequence identity, more preferably at least about 90% sequence identity, even more preferably at least about 95% sequence identity, and most preferably at least about 98% sequence identity with the light chain region as shown in SEQ ID NO:8 are included within the scope of the present invention. Additionally, a humanized antibody comprising a heavy chain region that exhibits at least about 85% sequence identity, more preferably at least about 90% sequence identity, even more preferably at least about 95% sequence identity, and most preferably at least about 98% sequence identity with the heavy chain region as shown in SEQ ID NO:5 are included within the scope of the present invention.

The DNA segments typically further comprise an expression control DNA sequence operably linked to the humanized antibody coding sequences, including naturally-associated or heterologous promoter regions. Preferably, the expression control sequences will be eukaryotic promoter systems in vectors capable of transforming or transfecting eukaryotic host cells, but control sequences for prokaryotic hosts may also be used. Once the vector has been incorporated into an appropriate host, the host is maintained under conditions suitable for high level expression of the nucleotide sequences and, as desired, the collection and purification of the variable light chain, heavy chain, light/heavy chain dimers or intact antibody, binding fragments or other immunoglobulin form may follow. (See, S. Beychok, Cells of Immunoglobulin Synthesis, Academic Press, N.Y. (1979)). Single chain antibodies may also be produced by joining nucleic acid sequences encoding the VL and VH regions disclosed herein with DNA encoding a polypeptide linker.

Prokaryotic hosts, such as E. coli, and other microbes, such as yeast, may be used to express an antibody of the present invention. In addition to microorganisms, mammalian tissue cell culture may also be used to express and produce the antibodies of the present invention. Eukaryotic cells may be preferred, because a number of suitable host cell lines capable of secreting intact immunoglobulins have been developed in the art, and include the CHO (chinese hamster ovary) cell lines, various COS (African green monkey fibroblast cell line) cell lines, HeLa cells, myeloma cell lines, and hybridomas. Expression vectors for these cells can include expression control sequences, such as a promoter or enhancer, and necessary processing

information sites, such as ribosome binding sites, RNA splice sites, polyadenylation sites, and transcriptional terminator sequences, all known in the art.

The vectors containing the DNA segments of interest (e.g., the heavy and/or light chain encoding sequences and expression control sequences) can be transferred into the host cell by well-known methods, which vary depending on the type of cellular host. For example, calcium chloride transfection is commonly utilized for prokaryotic cells, whereas calcium phosphate treatment or electroporation may be used for other cellular hosts. (See, e.g., T. Maniatis et al., Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Press (1982)).

Once expressed, the whole antibodies, their dimers, individual light and heavy chains, or other immunoglobulin forms of the present invention, can be purified according to standard procedures in the art, including ammonium sulfate precipitation, affinity columns, column chromatography, gel electrophoresis and the like. Substantially pure immunoglobulins of at least 90 to 95% homogeneity are preferred, and 98 to 99% or more homogeneity are most preferred, for pharmaceutical uses.

The antibodies of the present invention will typically find use in treating antibody mediated and/or T cell mediated disorders. Typical disease states suitable for treatment include cancer, infectious diseases and autoimmune diseases such as multiple sclerosis, rheumatoid arthritis, systemic lupus erythematosus, and myesthenia gravis.

The invention provides pharmaceutical compositions comprising at least one humanized antibody of the present invention formulated with a pharmaceutically acceptable carrier. Some compositions include a combination with other agents used for the treatment of cancer, such as chemotherapeutics, infectious diseases or autoimmune disease as stated above. Alternatively, the pharmaceutical composition can comprise or be co-administered with another agent that can include a second antibody, a co-stimulatory molecule or immunomodulator.

The antibodies and pharmaceutical compositions of the present invention are particularly useful for parenteral administration, i.e., subcutaneously, intramuscularly or intravenously. The pharmaceutical compositions for parenteral administration will commonly comprise a solution of the antibody dissolved in an acceptable carrier, preferably an aqueous carrier. A variety of aqueous carriers can be used, all well

known in the art, e.g., water, buffered water, saline, glycine and the like. These solutions are sterile and generally free of particulate matter. These pharmaceutical compositions may be sterilized by conventional well known sterilization techniques. The compositions may contain pharmaceutically acceptable auxiliary substances as required to approximate physiological conditions such as pH adjusting and buffering agents, toxicity adjusting agents and the like, for example, sodium acetate, sodium chloride, potassium chloride, calcium chloride, sodium lactate, human albumin, etc.

The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will generally be that amount of the composition which produces a therapeutic effect. It is especially advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Those skilled in the art would be able to formulate dosage unit forms according to standard known techniques dictated by and directly dependent on the unique characteristics of the active compound and the particular therapeutic effect to be achieved and the limitations inherent in the art of compounds such an active compound for the treatment of sensitivity in individuals.

Effective doses of the compositions of the present invention, for the treatment of cancer, infectious diseases and autoimmune diseases described herein vary depending upon many different factors, including means of administration, target sit, physiological state of the patient, other medications administered and whether the treatment is prophylactic or therapeutic. Notwithstanding these factors, for administration with an antibody of the present invention, the dosage ranges from about 1.0 to 10.0 mg/kg. Antibodies are typically administered on multiple occasions. Intervals between single dosages can be weekly, monthly or bi-monthly depending on the individual needs of the patient. Those skilled in the art would be able using standard pharmacological methodologies to determine the necessary treatment regime depending on the specific disease and severity of the condition to be treated.

The compositions containing antibodies of the present invention can be administered for prophylactic and/or therapeutic treatments. In therapeutic application, compositions are administered to a patient already suffering from a disease, in an amount sufficient to cure or at least partially arrest the disease and its complications. An amount adequate to accomplish this is defined as a

"therapeutically effective dose". Amounts effective for this use will depend upon the severity of the disease state and the general state of the patient's own immune system, and can be determined by one skilled in the art.

In prophylactic applications, compositions containing antibodies of the present invention are administered to a patient not already in the disease state to enhance the patient's resistance (enhance an immune response). Such an amount is defined to be a "prophylactically effective dose". In this use, the precise amounts again depend upon the patient's state of health and general level of immunity. A preferred prophylactic use is for the prevention of tumor recurrence.

The following examples are for illustrative purposes only and do not limit the scope of the invention, which is defined only by the claims.

Examples:

I. Immunization and Screening Protocols

A. Immunization

Sprague Dawley rats were immunized with a recombinant fusion protein consisting of the extracellular domain of H4-1BB fused to the constant domains of a human IgG1 antibody. The hu4-1BBIg fusion protein contained a site for cleavage by the protease thrombin which was situated between the 4-1BB and the Ig portion of the molecule. Animals were immunized with 40 μg of H4-1BB intraperitonally (i.p.) in RIBI adjuvant (RIBI Immunochemical) and subsequently boosted i.p. with 20-40 μg of hu4-1BB-Ig or H4-1BB in which the Ig portion of the molecule was cleaved by thrombin digestion. Three days prior to the fusion, animals were boosted i.p. and intravenous (i.v.) with 20 μg of hu4-1BB. For the fusion, spleen and lymph nodes were harvested from an immunized animal and fused with X63-Ag8.653 mouse myeloma cell line using standard protocols (J. Kearney et al., J. Immunol. 123:1548-1550 (1979); J. Lane, Immunol. 81:223-228 (1985)). Cell suspensions from each fusion were seeded into 96-well cell culture plates at 100,000 cells per well.

B. Screening and Cloning

To determine specificity of the mAbs to human 4-1BB, cell culture supernatants were screened by an ELISA (enzyme-linked immunosorbent assay) method. Cell culture supernatants were tested on plates coated with purified hu4-

1BBIg fusion protein (0.2 μg/ml), or against a similarly constructed irrelevant fusion protein, CTLA4-Ig (0.2 μg/ml). Soluble human Ig (50 μg/ml) was added to block anti-human Ig reactivity. Cell culture supernatants were incubated for two hours at ambient temperature, wells were washed and a peroxidase-conjugated goat anti-rat IgG antibody detected the binding of the antibodies. Reactivity of the supernatants with H4-1BB and not with CTLA4-Ig revealed the presence of an antibody specific for human 4-1BB. Positive master wells were cloned by a limiting dilution method.

Monoclonal antibodies were further characterized to determine their ability to block 4-1BB-4-1BBL interaction and for their capacity to induce IFN-γ synthesis in vitro. These studies led to the selection of mAb 39E3, an IgG1, non-blocking mAb that induced IFN-γ synthesis in co-stimulation assays. The invention also includes the hybridoma cells producing the mAb 39E3 (ATCC Accession Number ATCC-PTA-5326). The 39E3 mAb was affinity purified on protein G by standard methods (Gammabind Plus, Pharmacia, MI), and eluted with Immunopure Ig Elution buffer. The eluted antibody was dialyzed against PBS (phosphate buffered saline) before use. The endotoxin concentration of the purified material used in *in vitro* co-stimulatory assays was < than 0.5 EU/mg.

II. Construction of a Humanized 39E3 Antibody

To minimize the immunogenicity of the rat anti-human 4-1BB antibody when administered to humans, a humanized form of the antibody was generated in which the rat hypervariable regions of the antibody (CDR) were grafted onto human framework sequences. In addition, the antibody was made of the IgG4 isotype because of the reduced effector functions of this isotype. A mutation in the hinge region of the IgG4 was introduced to reduce the heterogeneity of disulfide formation (S. Angal et al., Molec. Immunol.vol.30, 105-108, 1993).

A. Humanization of Variable Regions of anti-H4-1BB mAb 39E3

1. Isolation of RNA cDNA Synthesis and PCR (Polymerase Chain Reaction) Amplification

RNA was isolated from 39E3 hybridoma cells using an mRNA isolation kit (Stratagene, LaJolla, CA). The cDNA was generated from the RNA using the SuperScript RT-PCR kit (Gibco, BRL, Rockville, MD). The cDNA was generated

using an IgG1-specific or a C[kappa]-specific anti-sense primer to obtain the VH and VL regions, respectively. The primers were designed from published sequences for mouse and rat immunoglobulins. The cDNAs were purified using GENECLEAN. (Bio101, LaJolla, Calif.) and subsequently polyG-tailed with 10 mM dGTP and terminal deoxynucleotidyl transferase (Stratagene, LaJolla, CA) for 1 hour at 37 °C. Poly G-tailed cDNAs were purified using GENECLEAN. Two µl of each cDNA were amplified by anchor-PCR (Saiki et al., 1988. Science 239:487-491) in a total volume of 100 µl using 20 µ mol of each dNTP, 100 pmol of sense and antisense primers, and 2U Taq polymerase. The sense primer contained a region complementary to the polyG tail (Loh et al., 1989. Science 243:217-220). Reactions were carried out in a Perkin-Elmer Cetus thermal cycler (Norwalk, CT) with a 33 cycle program of 30 sec. denaturation at 94 °C, 90 sec. annealing at 45 °C, and 90 sec. extension at 72 °C.

PCR-amplified VL and VH fragments were digested with EcoR I and Xba I, ligated into the pUC18 vector and transformed in DH5α E. coli (Gibco, BRL, Rockville, MD).

2. Parental Antibody Variable Light and Heavy Sequences

Clones containing the VL or VH were identified by standard DNA sequencing techniques. The deduced amino acid sequence for clone 39E3 VL and VH, respectively, are provided in SEQ ID NOS:1 and 2.

B. Determination of Human Templates for 39E3 VL and VH

The rat 39E3 VL (kappa) and VH sequences were used to search the IgGe (germline) data set for rat germline nucleotide sequences with the closest homology to 39E3 VL with a FASTA search using only nucleotides encoding the mature peptide. This search produced two rat sequences with high homology, the best match designated "RNIGKY3" (GenBank Accession Number X16129).

The human germline amino acid sequence with closest homology to 39E3 VL was determined by performing a FASTA search on the IgP (protein) data set. This data set contained both germline and rearranged sequences. After discarding the rearranged sequences, the best homology match was found with the germline sequence designated "HKV4-1" (GenBank Accession Number Z00023).

The rat nucleotide sequence with the closest homology to 39E3 VH was also determined by performing a BLAST search of the rat cDNA data set using only nucleotides encoding the mature peptide as the query sequence. The search resulted in the rat immunoglobulin variable region sequence (GenBank Accession Number M87785) which showed significantly better homology than the other rat sequences.

The human germline amino acid sequence with the closest homology to 39E3 VH was determined by performing a FASTA search on the IgP data set. The best match was found with the "hhv3-7" germline sequence (GenBank Accession Number Z12354).

C. Refinement of 39E3 VL and VH Humanization Templates.

The canonical loop structures for the antigen binding loops L1, L2, and L3 of the VL domain and H1 and H2 of the VH domain were identified, and conserved residues that were defined as structural determinants (C. Chothia et al., J. Mol. Biol. 196:901 (1987); A. Lesk et al., In Antibody Engineering, A Practical Guide, W. H. Freeman and Co., pp 1-38 (1992)) were retained as rat residues.

The refined VL and VH humanization templates were used to search the Brookhaven databank for homologous sequences in which the crystal structure had been solved.

D. Determination of the J-region Templates

The best human J kappa sequence was selected by homology to the rat J kappa sequence in E. Kabat et al., Sequences of Proteins of Immunological Interest, 4th Edition, U.S. Health and Human Services, Washington, D.C. (1987). Similarly, the best human JH sequence was selected by homology to the rat JH sequence in E. Kabat et al., supra. The proposed sequences were then used to identify antibodies for which three-dimensional structures were available with the closest possible sequence match. This information was used to explore possible incompatible contact places (domain-domain interactions and framework-loop interactions) but none were found.

E. Humanization of the 39E3 VL

The oligonucleotide primers used to humanize the 39E3 VL are listed in Table 1.

TABLE 1

Oligonucleotide Primer	Sequence
39E3VL-for1	SEQ ID NO:9
39E3VL-for2	SEQ ID NO:10
39E3 VL-for3	SEQ ID NO:11
39E3 VL-Rev1	SEQ ID NO:12
39E3 VL-Rev2	SEQ ID NO:13

The amplified humanized 39E3 VL DNA was then ligated into pUC19 and was used to transform E. coli (strain DH50 alpha) per standard techniques. Plasmid DNA from individual clones was sequenced to verify proper fragment assembly of the humanized 39E3 VL.

F. Humanization of the 39E3 VH

The oligonucleotide primers used to humanize the 39E3 VH are listed in Table 2.

TABLE 2

Oligonucleotide Primer	Sequence
39E3VH-for1	SEQ ID NO:14
39E3VH-for2	SEQ ID NO:15
39E3 VH-for3	SEQ ID NO:16
39E3VH-for4	SEQ ID NO:17
39E3VH-rev1	SEQ ID NO:18
39E3VH-rev2	SEQ ID NO:19
39E3VH-rev3	SEQ ID NO:20

The amplified humanized 39E3 VH DNA was then ligated into pUC19 and was used to transform E. coli (strain DH5 α) per standard techniques. Plasmid DNA from individual clones was sequenced to verify proper fragment assembly of the humanized 39E3 VH.

G. Generation of a Cell Line Producing Humanized 39E3.G4 Antibody

A Chinese hamster ovary cell line (CHO DG-44) was transfected with the plasmid expression vectors coding the heavy and light chain of 39E3. The heavy and light chains of 39E3 were cloned into pD17 and pD16 expression vectors,

respectively. Both vectors are derived from the pcDNA3, and contain the murine dihydrofolate reductase (DHFR) gene under the control of the enhancerless SV40 promoter. Transfectants were grown up and selected using increasing concentrations of methotrexate (MTX). In vitro assays were performed to confirm that the humanization procedure did not alter the characteristics of the 39E3 antibody.

FIG. 1 shows a plasmid map of pD17-H39E3-2.h4a which contains a nucleotide sequence of 7033 nucleotides (SEQ ID NO:3) that encodes a heavy chain amino acid sequence of 460 amino acids (SEQ ID NO:5). FIGS. 2A-2G show the nucleotide sequence of the plasmid pD17-H39E3-2.h4a (coding strand (SEQ ID NO:3) and complementary strand (SEQ ID NO:4)) and the heavy chain amino acid sequence (SEQ ID NO:5) encoded by nucleotides 693 to 2071 of the coding strand (SEQ ID NO:3). As shown in FIGS. 2A-2G, the heavy chain amino acid sequence includes a CDR1 comprising amino acids 50 to 54 of SEQ ID NO:5, a CDR2 comprising amino acids 69 to 85 of SEQ ID NO:5, and a CDR3 comprising amino acids 118 to 122 of SEQ ID NO:5.

FIG. 3 shows a plasmid map of pD16-H39E3.L1 which contains a nucleotide sequence of 8874 nucleotides (SEQ ID NO:6) that encodes a light chain amino acid sequence of 240 amino acids (SEQ ID NO:8). FIGS. 4A-4H show the nucleotide sequence of the plasmid pD16-H39E3.L1 (coding strand (SEQ ID NO:6) and complementary strand (SEQ ID NO:7)) and the light chain amino acid sequence (SEQ ID NO:8) encoded by nucleotides 633 to 1034 and 1409 to 1726 of the coding strand (SEQ ID NO:6). As shown in FIG. 4A-4H, the light chain amino acid sequence includes a CDR1 comprising amino acids 44 to 60 of SEQ ID NO:8, a CDR2 comprising amino acids 76 to 82 of SEQ ID NO:8, and a CDR3 comprising amino acids 115 to 123 of SEQ ID NO:8.

Single-stranded DNA isolated and the H and L chain variable region genes of the humanized antibodies of the invention was sequenced by the fluorescent dideoxynucleotide termination method (Perkin-Elmer, Foster City, CA).

III. In Vitro Characterization of hu39E3.G4

In vitro studies were conducted with the humanized form of 39E3, hu39E3.G4 to compare its activities to the parent mAb, 39E3.

A. Kinetic Analysis of Anti-4-1BB Antibodies

Kinetic binding studies to show the binding affinity of hu39E3.G4 to 4-1BB were performed using surface plasmon resonance to investigate the kinetic properties of mAb 39E3 and hu39E3.G4. These studies were carried out on a BIAcore 3000 instrument (BIAcore Inc., Piscataway, NJ). Dilutions of the antibodies were injected under identical conditions over sensorchip surfaces of immobilized H4-1BB.

Human 4-1BB receptor was immobilized covalently to a low density on a carboxy-methylated dextran surface of a BIAcore sensorchip (BIAcore Inc., Piscataway, NJ). Through primary amino groups the fusion protein, injected at 2 μg/mL in 10 mM acetate buffer, pH 5.0, bind to an EDC/NHS-activated surface. Unoccupied active esters were subsequently blocked by injection of an excess of ethanolamine. After regenerating with 10 mM glycine, pH 2.0 the surface was ready for binding studies. Antibodies 39E3 and hu39E3.G4 were diluted to concentrations between 10 nM and 100 nM using HBS-EP buffer. All mAb dilutions were injected over two flow cells (FC) at a flow rate of 25 μl/minute. FC1 served as a negative control, FC2 had low density of human 4-1BB (557 RU). Bound anti-human 4-1BB mAbs were removed by regeneration with 10 mM Glycine pH 1.75.

Kinetic parameters were calculated with BIAevaluation program (version 3.1) (BIAcore Inc., Piscataway, NJ). A global curve fit analysis was performed using a Bivalent Analyte Model (BIAcore Inc. Piscataway, NJ). As shown in FIG. 5, the global fit analysis algorithm of the BIAevaluation software finds the single set of kinetic constants k_a and k_d that best fit all the association and dissociation data at the same time. The binding affinities for the parental mAb, 39E3, and the humanized anti-H4-1BB mAb are shown below in Table 3.

TABLE 3

Antibody	Type	K_{a1} (1/Ms)	K_{d1} (1/s)	K_{A1} [1/M]	K_{D1} [nM]
39E3	rat IgG_1	7.07×10^3	4.77×10^{-5}	1.48×10^8	6.7
hu39E3.G4	humanized IgG_4	4.74×10^3	2.53×10^{-5}	1.87×10^8	5.3

Taken together, the studies showed that hu39E3.G4 binds to H4-1BB with an on- and off-rate similar to its parental antibody,39E3, with affinities of 5.3 nM for hu39E3.G4 and 6.7 nM for the parental form.

B. Flow cytometric analyses

Flow cytometric analyses were conducted to determine binding of hu39E3.G4 and 39E3 to 4-1BB expressed on activated CEM cells (ATCC-CRL2265). Upregulation of 4-1BB on CEM cells was obtained by activation with PMA (10 ng/ml) and ionomycin (1 μM) for 18 hours. Activated cells, but not unstimulated cells, bound to 4-1BBL but not a protein control. For these studies, $1x10^6$ activated CEM cells were stained with 1 to 10 μg of the anti-4-1BB antibodies hu39E3.G4 and 39E3. Following incubation for 45 minutes on ice, cells were washed and incubated with a fluorescein-conjugated goat anti-rat IgG antibody or fluorescein conjugated goat anti-human IgG to detect binding of mAb 39E3 or hu39E3.G4, respectively. As shown in FIG. 6, the results from these analyses indicated that these antibodies did not show binding to unstimulated cells and their binding to PMA-ionomycin activated CEM was similar.

C. Hu39E3.G4 Does Not Block 4-1BB-4-1BBL Interaction

The antibodies were further characterized for their ability to affect 4-1BB receptor-ligand interaction. All experiments were carried out on a BIAcore 3000 instrument (BIAcore Inc., Piscataway, NJ). H4-1BB was immobilized covalently to a high density on a carboxy-methylated dextran surface of a BIAcore sensorchip (BIAcore Inc., Piscataway, NJ). Injections were conducted at 2 μg/mL in 10 mM acetate buffer, pH 5.0. Unoccupied active esters were subsequently blocked by injection of an excess of ethanolamine. Regeneration of the surface was done with 10 mM glycine, pH 2.0.

Purified samples of anti-4-1BB antibodies were diluted to concentrations between 200 and 1000 nM using HEPES buffered saline, pH 7.4, supplemented with 0.15 M NaCl and 0.005% surfactant P20 (HBS-EP). H4-1BB Ligand-CD8 fusion proteins (H4-1BBL) were used as source of H4-1BBL. To investigate whether hu39E3.G4 or mAb 39E3 have any effect on the binding of H4-1BBL to H4-1BB, experiments were conducted in which H4-1BBL was injected prior to anti-4-1BB antibodies, or vice versa wherein antibodies were injected before addition of H4-1BBL. Injections were performed at a flow rate of 5 μL/min. Bound ligand and antibodies were removed by regeneration with 10 mM glycine buffer, pH 2.0. As

shown below in Table 4 neither hu39E3.G4 nor mAb 39E3 affected the binding of H4-1BBL to H4-1BB.

TABLE 4

Analyte	Isotype	Bound At First Injection	Antibody Bound After Ligand Injection	Ligand Bound After Antibody Injection
Ligand		619	81	81
39E3	rat IgG1	1010	908	540
hu39E3.G4	human. IgG4	880	767	552

D. In Vitro Co-stimulation Assays

To demonstrate that hu39E3.G4 was an agonistic antibody, *in vitro* co-stimulation assays were carried out to show that when the antibody was added to human T cells, the T cells were stimulated with a sub-optimal concentration of CD3 and they enhanced IFN-γ synthesis.

This was demonstrated by assessing the ability of the anti-human 4-1BB hu39E3.G4 and mAb 39E3 to induce cytokine synthesis *in vitro*. Human PBMC were isolated from healthy volunteers by Histopaque-1077 (Sigma, St Louis, MO) density-gradient centrifugation, and T-cells were further purified by rosetting with sheep red blood cells. T-cells ($1x10^6$ cells/ml) were cultured in the presence of anti-CD3 antibody (HIT3a, Pharmingen, San Diego, CA) at 0.1 μg/ml and co-stimulated with the anti-human 4-1BB mAbs hu39E3.G4 or 39E3 (20 μg/ml) or a control antibody. Supernatants were harvested 72 hours later and assayed for IFN-γ by an ELISA kit available commercially (Pharmingen, San Diego, CA). As shown in FIG. 7, this study revealed that production of IFN-γ was enhanced in the presence of the anti-4-1BB antibodies hu39E3.G4 and 39E3 in the presence of sub-optimal concentrations of anti-CD3. Cytokine concentrations in supernatants are expressed as mean ± SD of triplicate wells.

IV. Anti-Tumor Efficacy Studies with Anti-Murine 4-1BB Antibody, mAb 1D8

In that hu39E3.G4 did not recognize murine 4-1BB, the anti-tumor effect of this antibody could not be evaluated in murine tumor models. Therefore, a monoclonal antibody to murine 4-1BB, mAb 1D8, which closely matched the

properties of hu39E3.G4, was used to assess the suitability of this antibody as an anti-cancer agent. Monoclonal antibody 1D8 is a rat IgG2a antibody that binds to murine 4-1BB, but does not cross-react with H4-1BB. Monoclonal antibody 1D8, similar to hu39E3.G4, is not immunogenic in mice, does not block the 4-1BB-4-1BB ligand interaction, induces IFN-γ synthesis in co-stimulation assays, and does not fix complement.

In vivo anti-tumor efficacy was evaluated in two different settings: as monotherapy and following implantation of irradiated tumor cells (cell-based vaccine). These effects were tested in two tumor models, M109 lung carcinoma and Lewis Lung/LM carcinoma.

A. M109 Lung Carcinoma Model

Balb/c mice (8-10 weeks old) were implanted s.c. (subcutaneous) with a 1 % brie of M109 tumors. Three days later the mice were randomized and separated into three groups, each of 10 mice. The treatment groups consisted of a control group, which received phosphate buffered saline (PBS, control vehicle), a group receiving an isotype matched immunoglobulin at the same dose as mAb 1D8, and a third group which received mAb 1D8 at 200 μg/mouse, every 7 days for three doses. For the vaccination protocol, mice received a s.c. vaccination of irradiated M109 cells (2% brie, 30 Gy, 23 minutes) two weeks prior to implantation of viable tumor cells on the opposite flank (1% brie). Treatments were administered one day following implantation of tumor cells.

As shown in FIG. 8A, the mAb 1D8 induced a modest, but significant, inhibitory effect on tumor growth when used as monotherapy. However, when combined with a cell based vaccine mAb 1D8 produced a significant reduction of tumor incidence in that M109 tumors did not grow in the majority of 1D8 treated mice, as shown in FIG. 8B.

B. Lewis Lung/LM Carcinoma

Similar experiments were conducted with the Lewis Lung/LM carcinoma tumor. C57/BL6 mice were implanted s.c. with $1x10^5$ Lewis Lung/LM cells. For the vaccination protocol, mice received a s.c. injection of irradiated Lewis Lung/LM cells ($1x10^5$ Lewis Lung/LM cells, 30 Gy, 23 min). Antibody treatments (200 μg/mouse) were administered i.v. weekly for three doses. When mAb 1D8 was administered as a

single agent, mAb 1D8 had no effect on tumor growth (FIG. 9A). However, in mice previously implanted with irradiated tumor cells two weeks earlier, mAb 1D8 significantly inhibited tumor growth (FIG. 9B).

C. Anti-Tumor Activity of Anti-4-1BB Antibody Is Dependent on Production of IFN-γ

Since anti-4-1BB antibodies induced IFN-γ synthesis in in vitro co-stimulatory assays, studies were conducted to determine whether IFN-γ played a role in the anti-tumor activity of anti-4-1BB mAbs.

DBA mice were implanted with P815 cells ($1x10^5$ cells) s.c., on day 0. Three days later, the mice received 100 or 400 μg/mouse of a neutralizing anti-IFN-γ antibody (RA46A2) alone or in combination with an efficacious dose of anti-4-1BB antibody, mAb 1D8 (200 μg/mouse). Control groups consisted of mice treated with vehicle (PBS), isotype control antibody (200 μg/mouse), mAb 1D8 alone (200 μg/mouse), and mAb 1D8 (200 μg/mouse) plus the isotype control antibody (200 μg/mouse). The results of this study (FIG. 10) indicate that addition of an IFN-γ neutralizing antibody partially reduced the anti-tumor effects of mAb 1D8, suggesting that induction of IFN-γ is one of the mechanisms by which the anti-4-1BB mAb exerts its anti-tumor effects. It is expected that hu39E3.G4 will have the anti-tumor activities observed with mAb 1D8.

Although the invention has been described in some detail by way of illustration and example for purposes of clarity and understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims.